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(54) **OFF-AXIS DETECTION FOR PROXIMITY OR GESTURE SENSOR**

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G06F 3/03 (2006.01)
G06F 3/01 (2006.01)

(52) **U.S. Cl.**
CPC ***G06F 3/0304*** (2013.01); ***G06F 3/017*** (2013.01)

(58) **Field of Classification Search**
CPC G06F 3/0304; G06F 3/042; G06F 3/0421
USPC 250/221, 551; 345/173, 175
See application file for complete search history.

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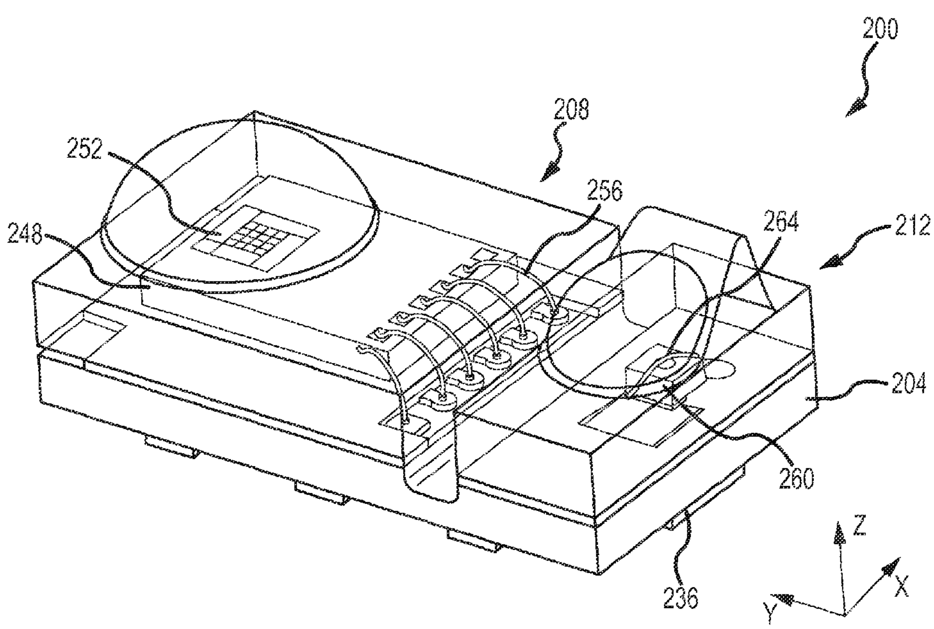
(57) **ABSTRACT**

An optical sensor for detecting at least one of proximity and gesture is disclosed. The optical sensor is configured to detect or sense an object that is located out of the sensor's primary axis. This off-axis detection is facilitated by projecting light emitted by a light source away from the sensor's primary axis and away from the direction in which the light was originally emitted by the light source. The light detector is also configured to detect the light that is being projected off-axis.

19 Claims, 12 Drawing Sheets



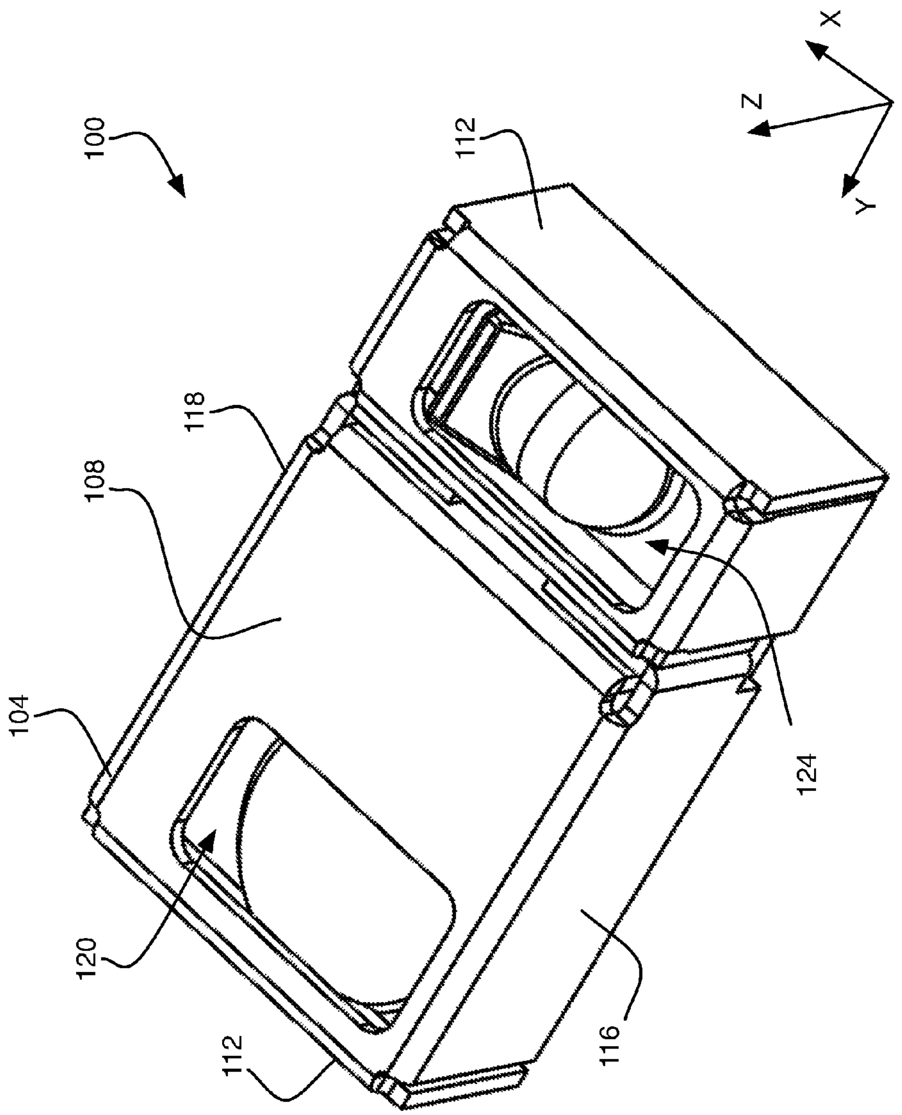


FIG. 1

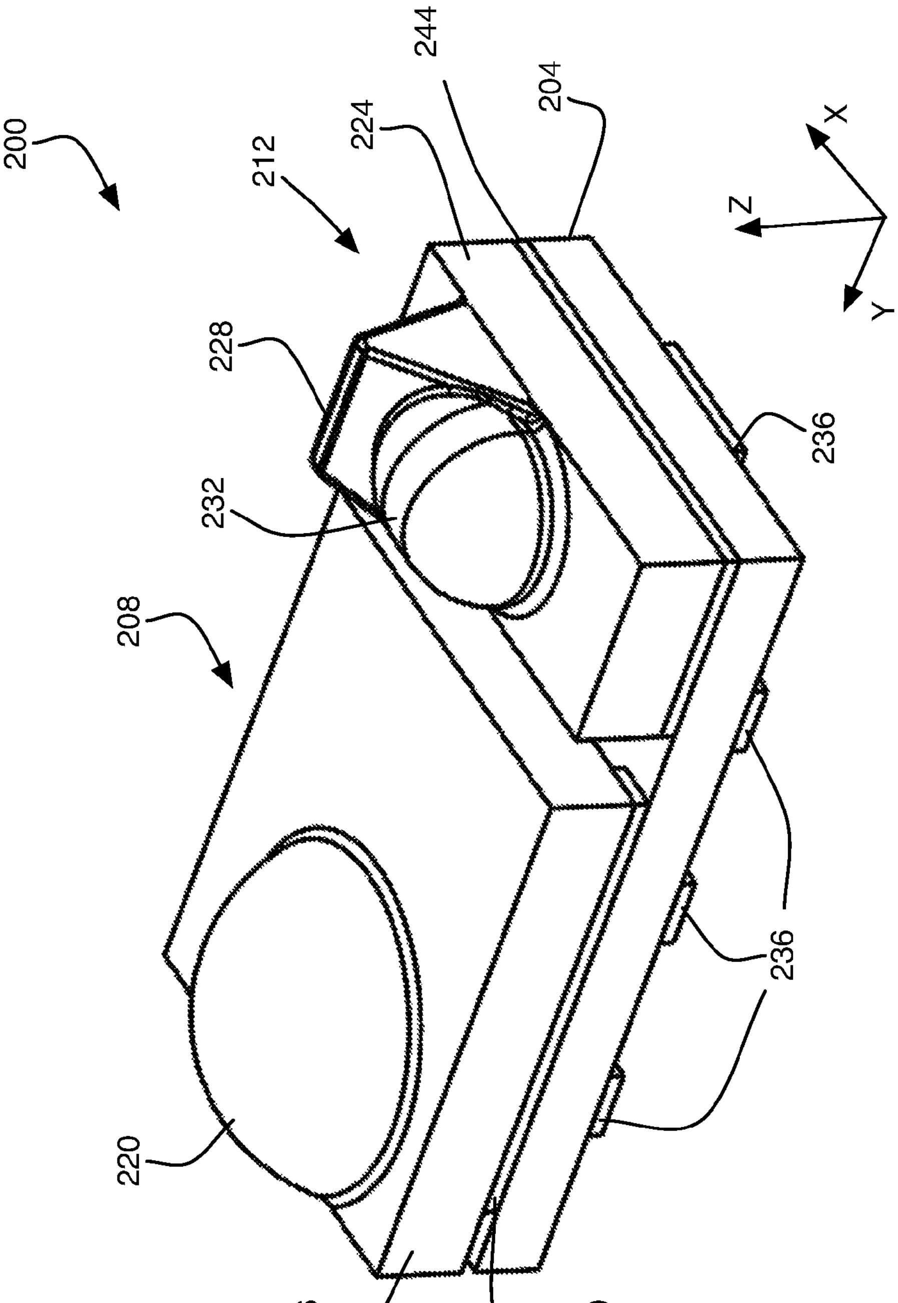


FIG. 2A

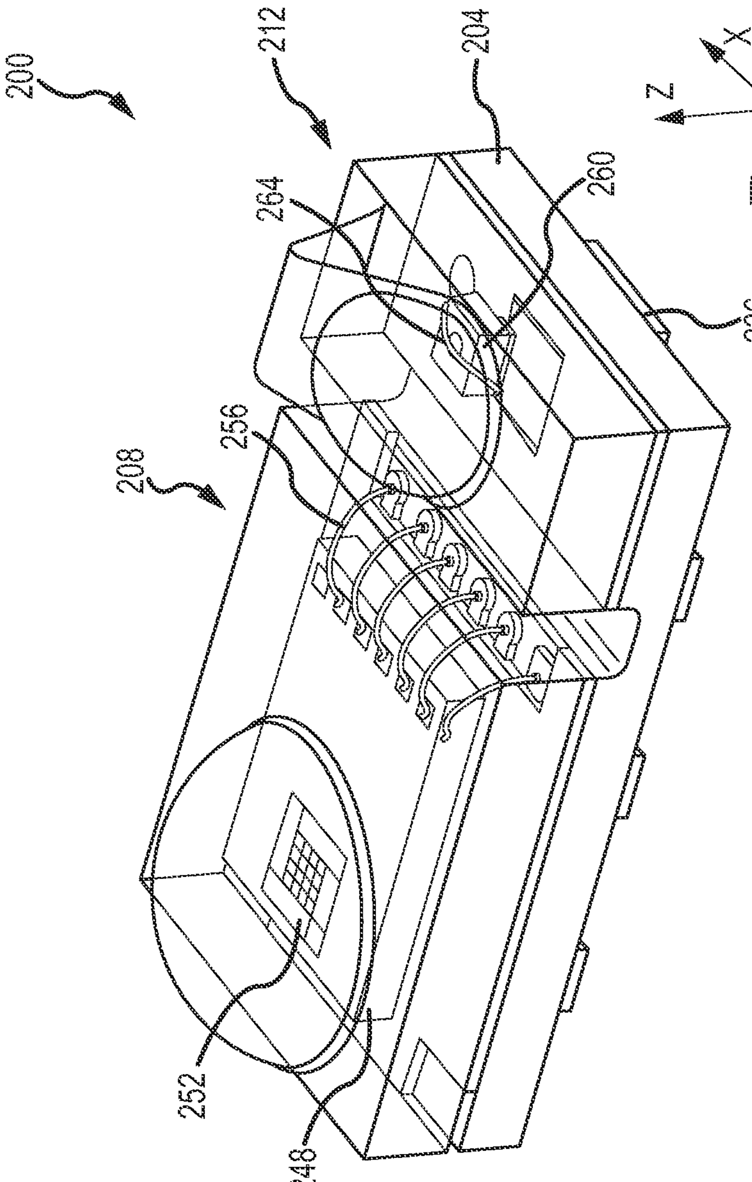


FIG.2B

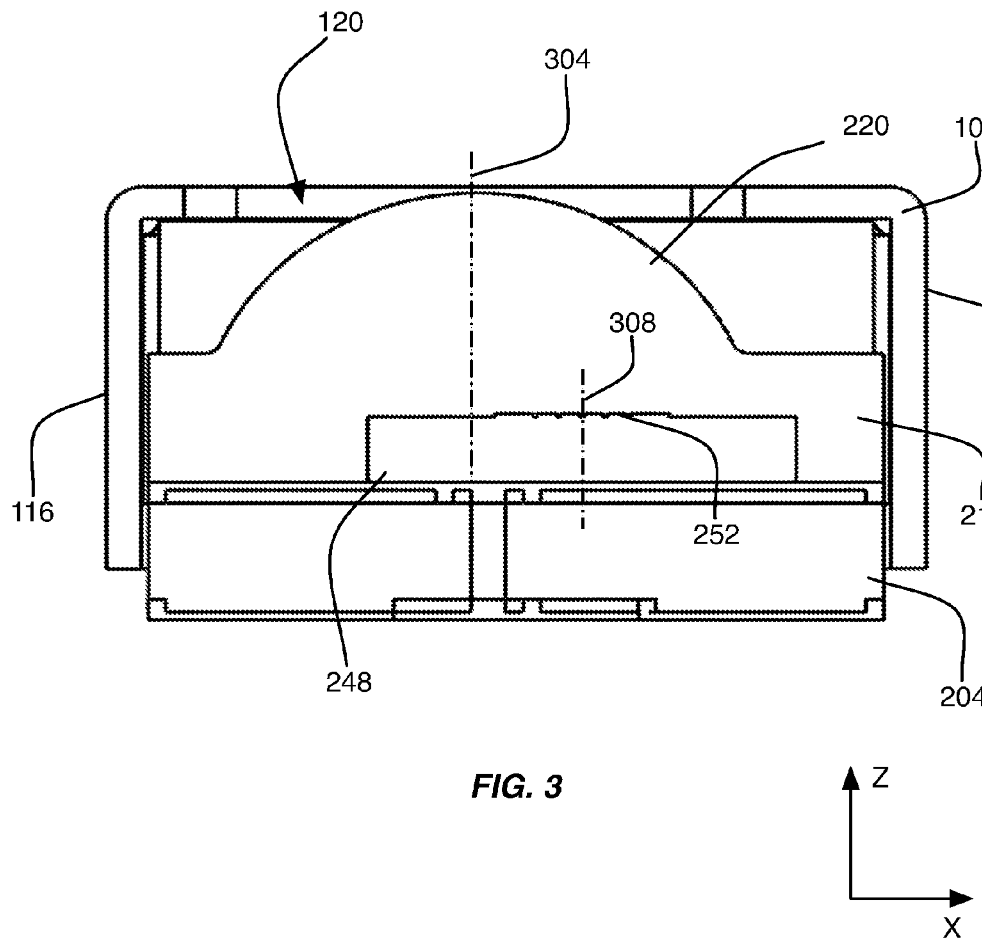


FIG. 3

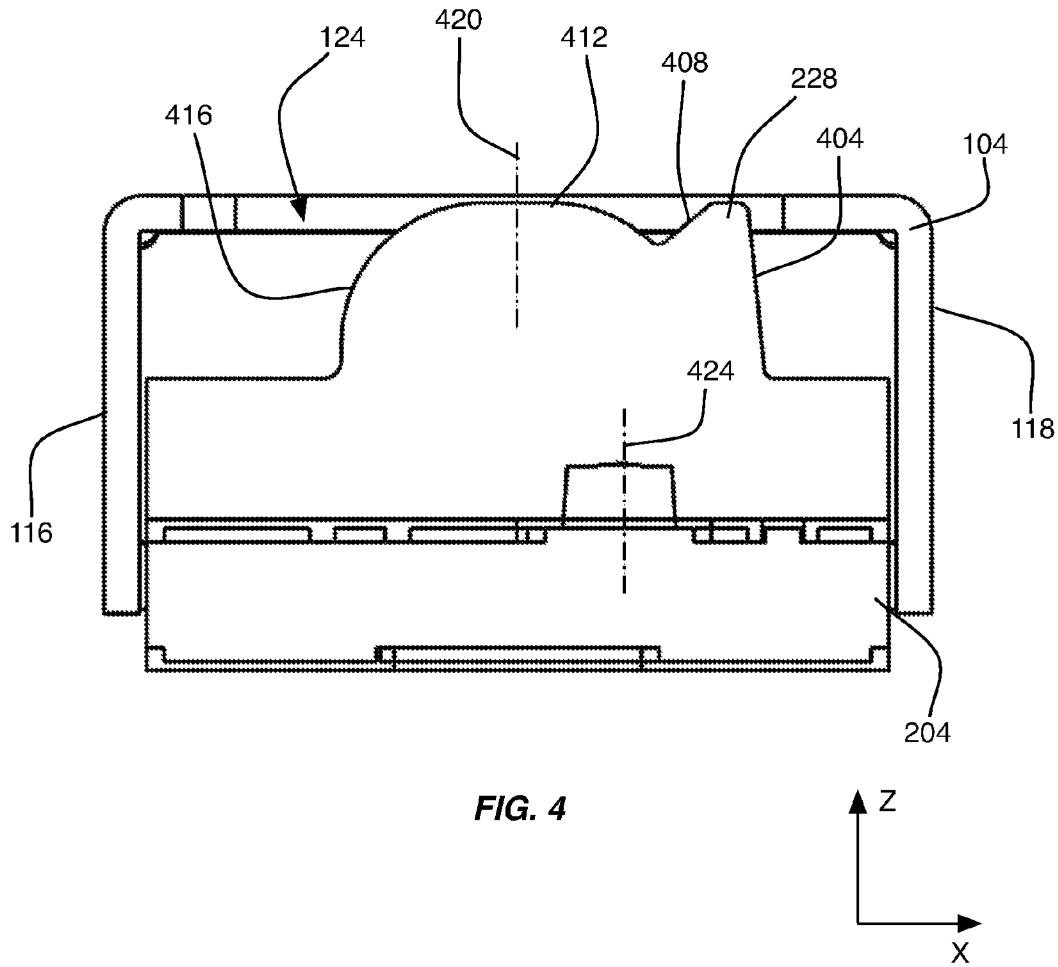


FIG. 4

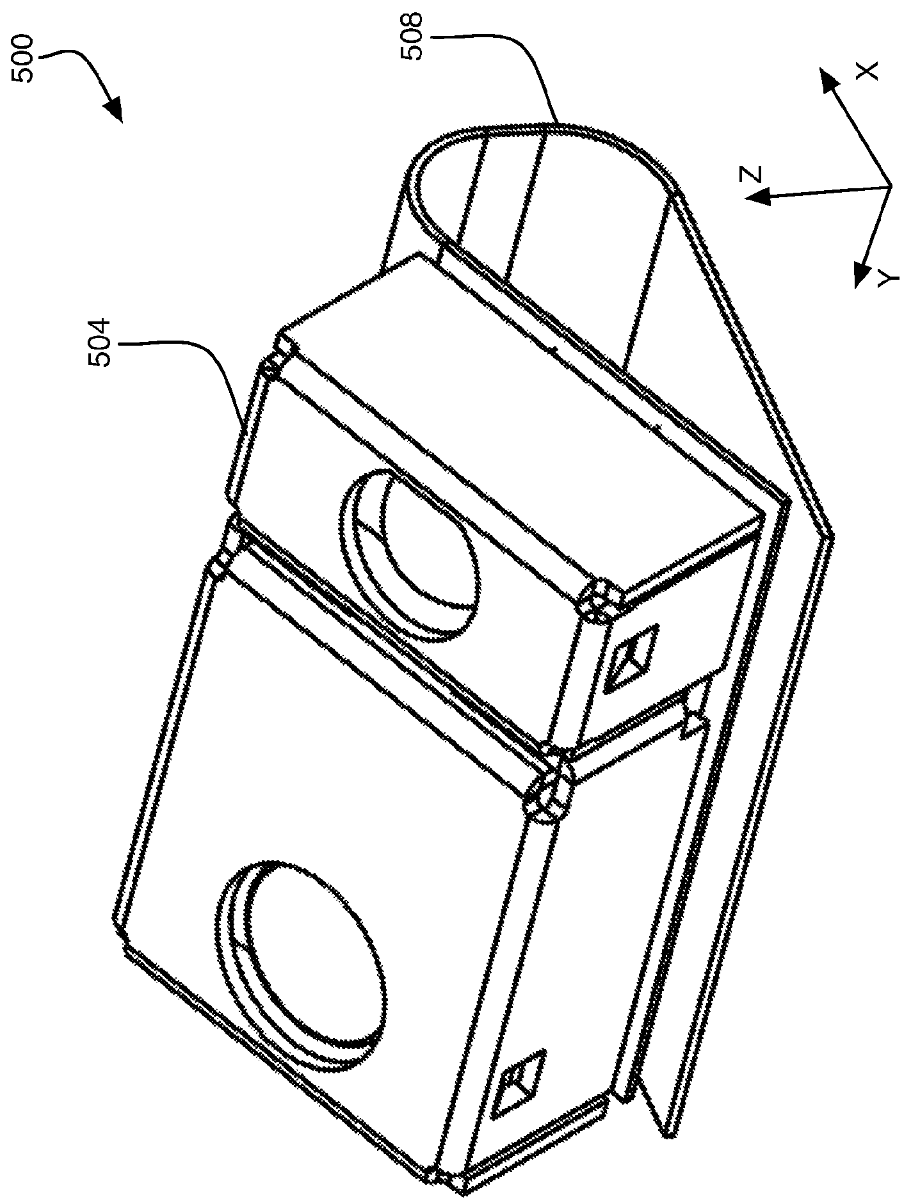


FIG. 5

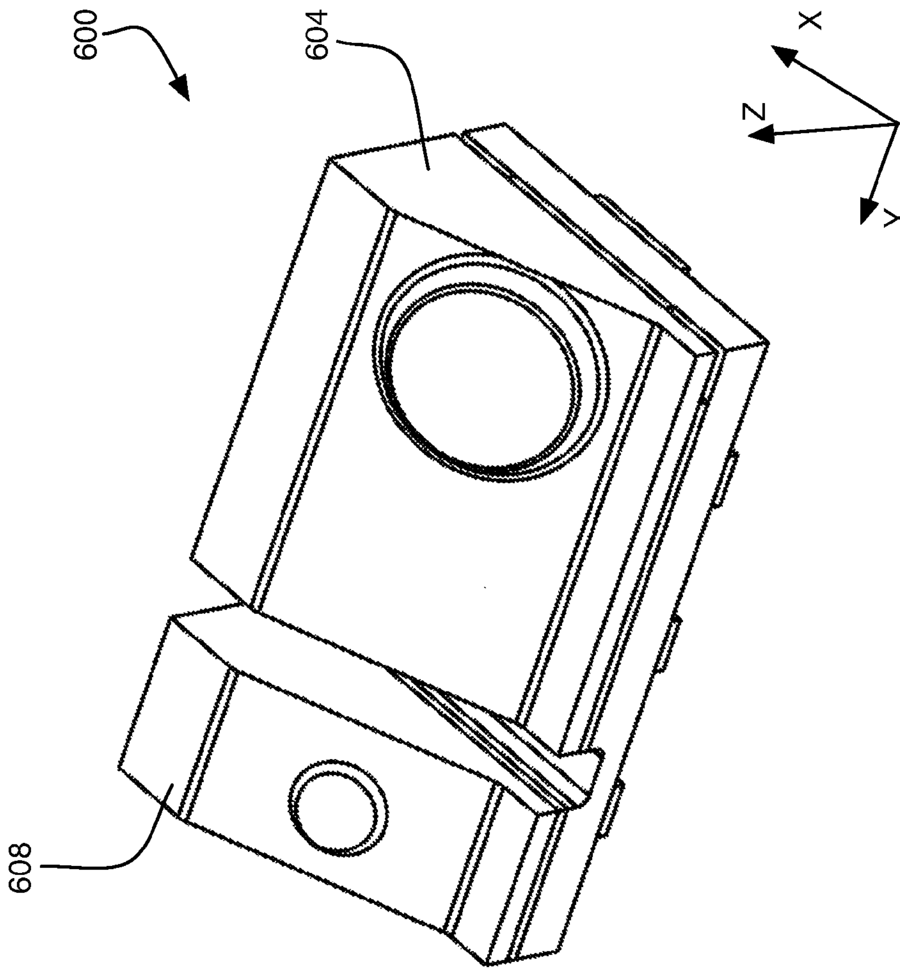


FIG. 6

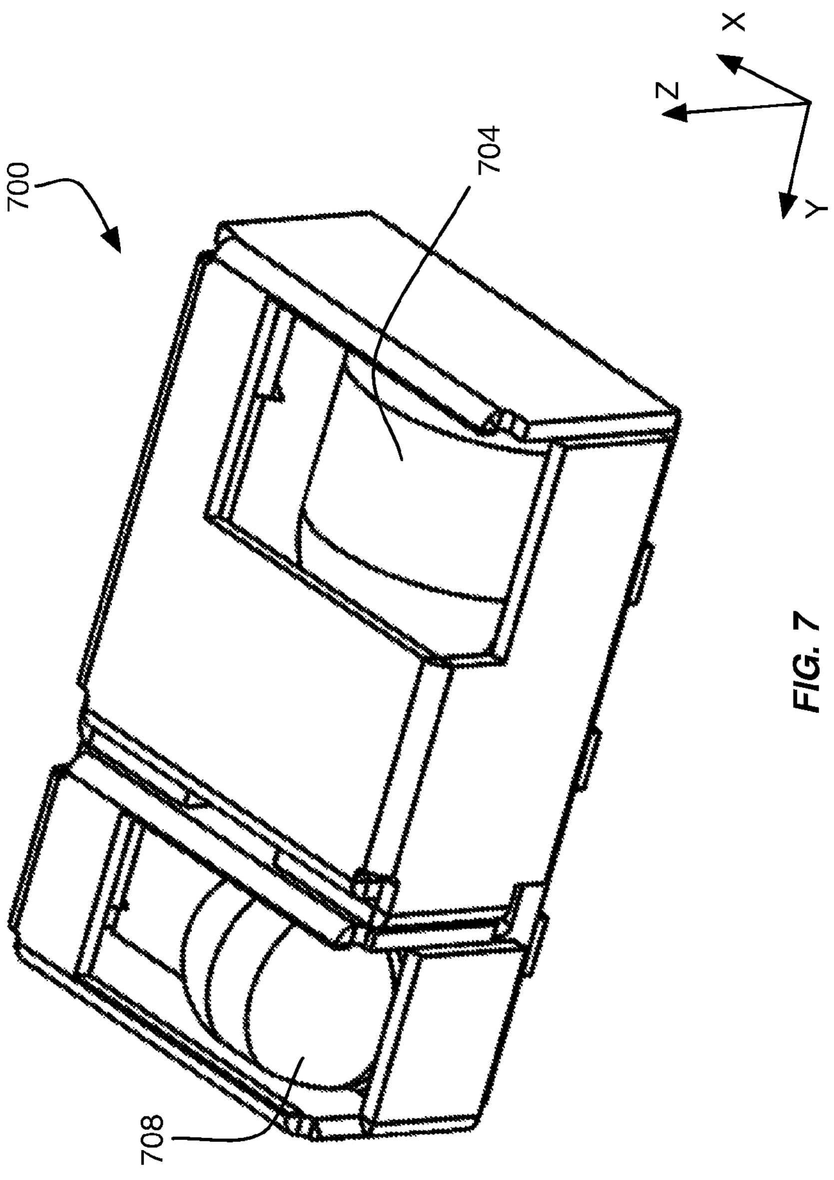


FIG. 7

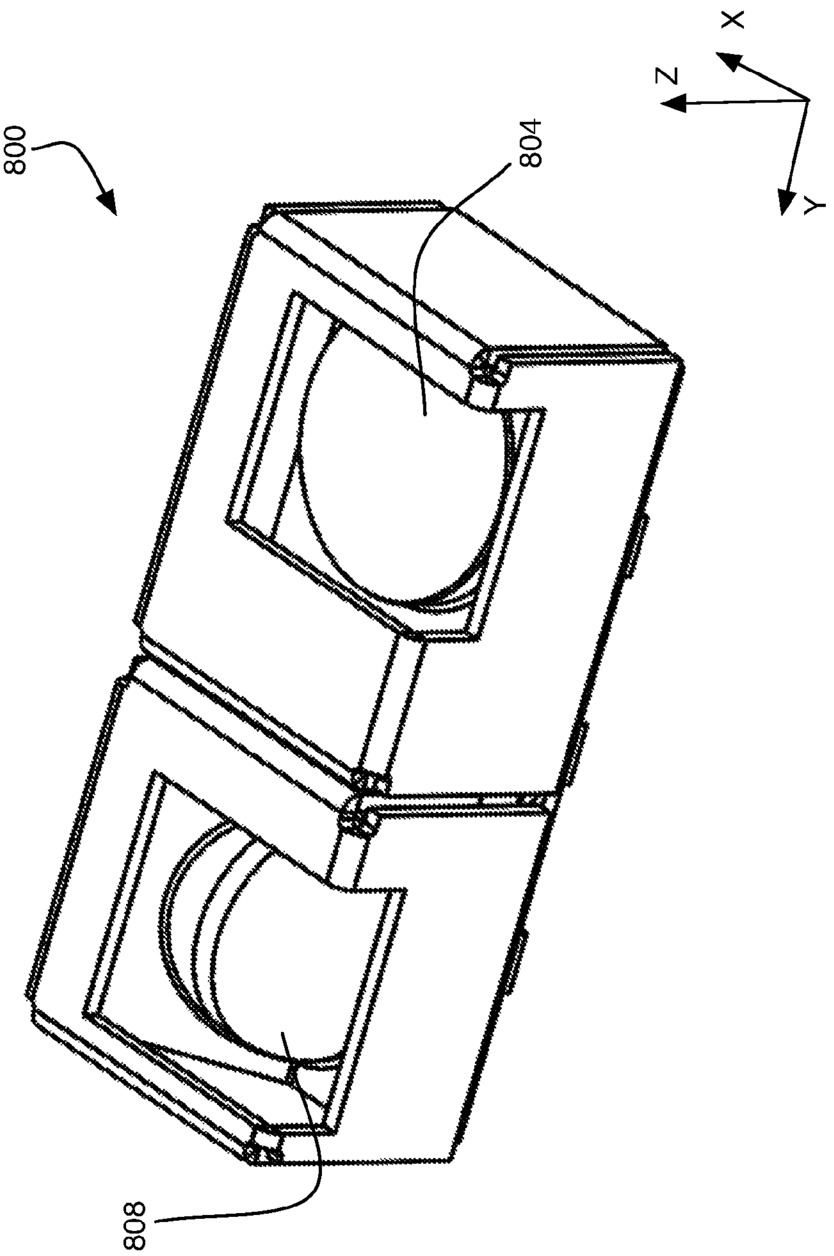


FIG. 8

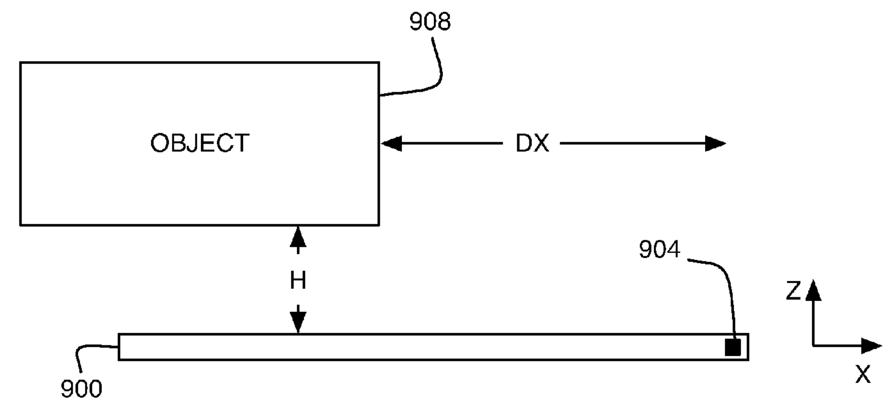


FIG. 9A

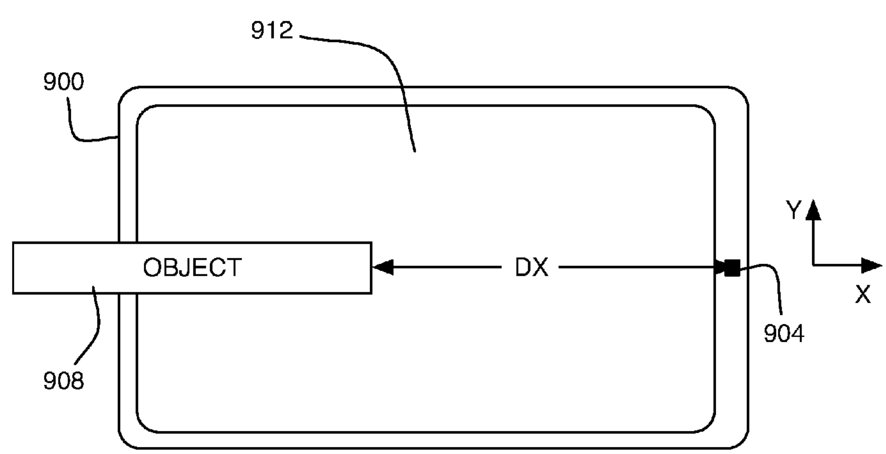


FIG. 9B

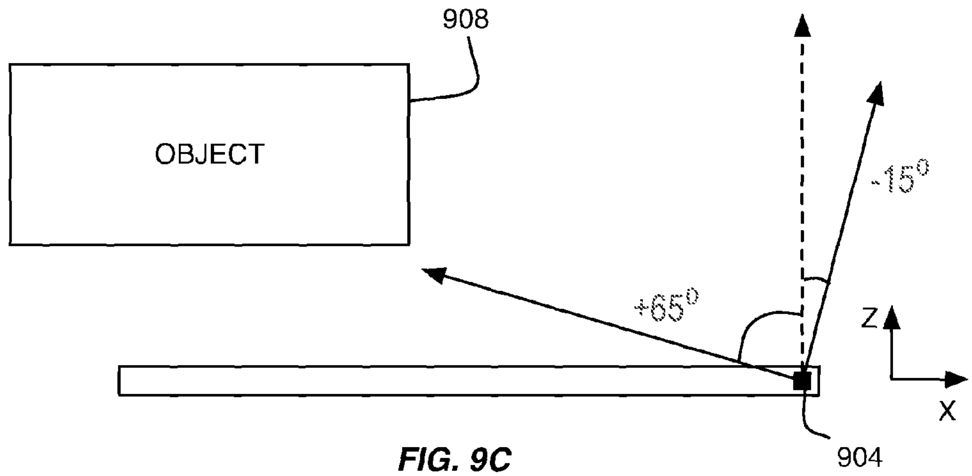


FIG. 9C

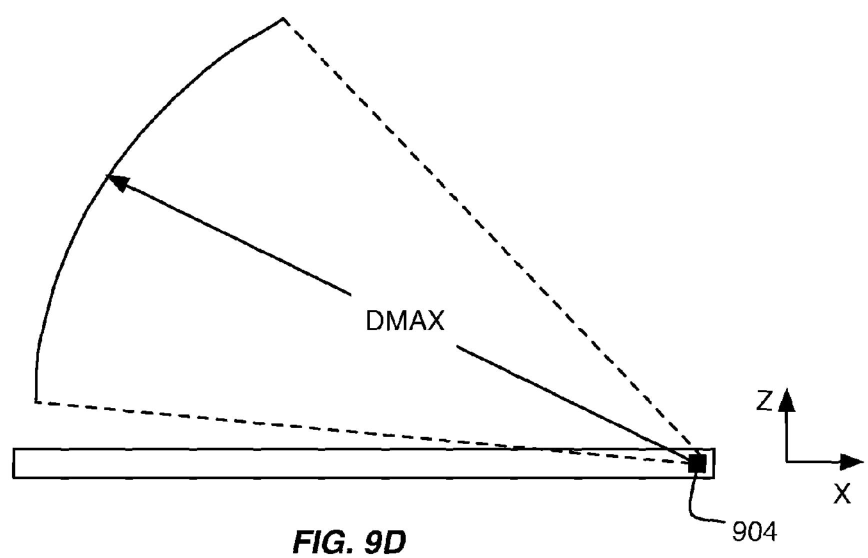


FIG. 9D

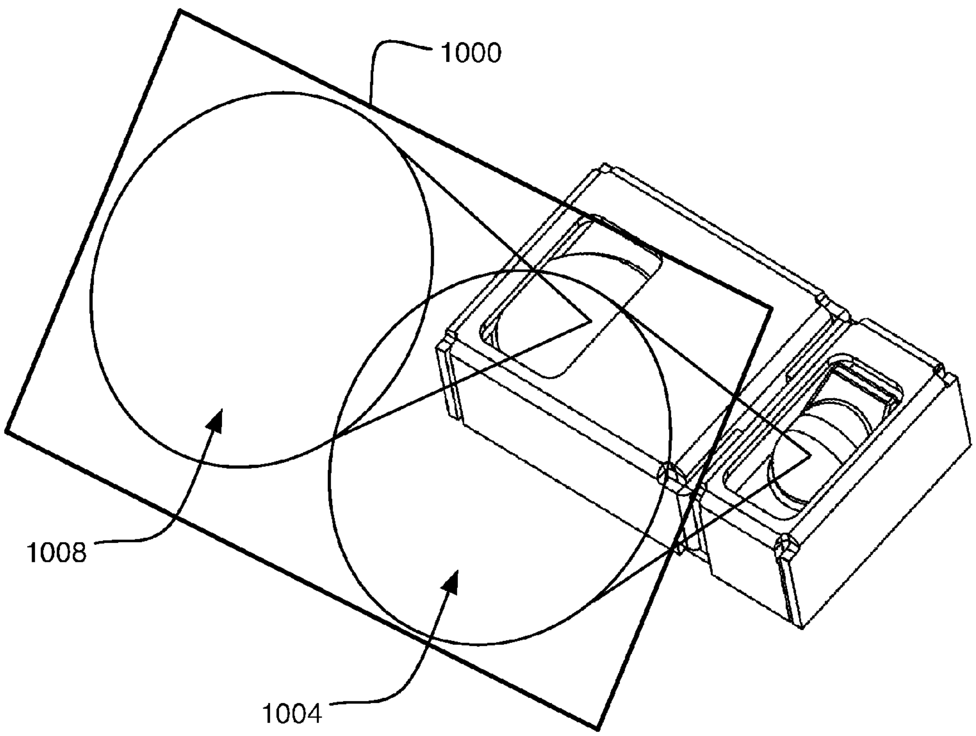


FIG. 10

OFF-AXIS DETECTION FOR PROXIMITY OR GESTURE SENSOR

FIELD OF THE DISCLOSURE

The present disclosure is generally directed toward sensors and more specifically toward optical sensors for detecting proximity or gesture.

BACKGROUND

Mobile communication devices, such as, for example, cellular telephones, smartphones, digital audio or video players, portable navigation units, laptop computers, personal digital assistants, tablets, netbooks, or the like are becoming increasingly popular. These devices may include, for example, a variety of sensors to support a number of applications in today's market. A popular market trend in sensor-based mobile technology may include, for example, applications that sense or recognize one or more aspects of a motion of a user relative to a mobile communication device and use such aspects as a form of a user input. For example, certain applications may sense or recognize waving gestures, finger gestures, air signatures, and the like of a user and may use such gestures as inputs representing various user commands in selecting music, playing games, estimating a location, determining navigation route, browsing through digital maps or Web content, authorizing transactions, or the like.

Proximity sensors are similar to some gesture sensors on mobile communication devices in that proximity sensors may also utilize light and imagers to detect a user's proximity to the sensor. Proximity can also be used as inputs to applications on the mobile communication device, although proximity inputs typically provide less information than gesture inputs. In other words, proximity inputs are usually binary (the user is either within a detectable proximity of the sensor or not) whereas gesture inputs may correspond to detecting certain motions or actions of a user with the gesture sensor.

A drawback to currently-available light-based sensors (proximity or gesture) is that the sensors are only capable of detecting proximity or gesture within a small detection window. More problematic is that the small detection window is required to be directly over the sensor itself. This means that user inputs at the sensor can only be detected when the user places a part of their body (or some other object) directly over the sensor. Requiring the user to provide such inputs in a small detection window has, to this point, limited the usefulness of light-based sensors in mobile communication devices. In particular, most users are interacting with a keypad or touch screen of the mobile communication device and do not want to have to change their interaction zone to some other location that is not coincident with the keypad or touch screen.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure is described in conjunction with the appended figures:

FIG. **1** depicts an isometric view of a sensor in accordance with embodiments of the present disclosure;

FIG. **2**A depicts a first isometric view of a sensor sub-assembly in accordance with embodiments of the present disclosure;

FIG. **2**B depicts a second isometric view of a sensor sub-assembly in accordance with embodiments of the present disclosure;

FIG. **3** is a cross-sectional elevational view in the x-z plane of a light detector incorporated in a sensor in accordance with embodiments of the present disclosure;

FIG. **4** is a cross-sectional elevational view in the x-z plane of a light source incorporated in a sensor in accordance with embodiments of the present disclosure;

FIG. **5** depicts an isometric view of a sensor in accordance with embodiments of the present disclosure;

FIG. **6** depicts an isometric view of a sensor in accordance with embodiments of the present disclosure;

FIG. **7** depicts an isometric view of a sensor in accordance with embodiments of the present disclosure;

FIG. **8** depicts an isometric view of a sensor in accordance with embodiments of the present disclosure;

FIG. **9**A depicts an elevational view of an electronic device incorporating a sensor in accordance with embodiments of the present disclosure;

FIG. **9**B depicts a top view an electronic device incorporating a sensor in accordance with embodiments of the present disclosure;

FIG. **9**C depicts a field of view range of a sensor in accordance with embodiments of the present disclosure;

FIG. **9**D depicts a viewing distance of a sensor in accordance with embodiments of the present disclosure; and

FIG. **10** depicts an image plane relative to a sensor in accordance with embodiments of the present disclosure.

DETAILED DESCRIPTION

The ensuing description provides embodiments only, and is not intended to limit the scope, applicability, or configuration of the claims. Rather, the ensuing description will provide those skilled in the art with an enabling description for implementing the described embodiments. It being understood that various changes may be made in the function and arrangement of elements without departing from the spirit and scope of the appended claims.

Various aspects of the present disclosure will be described herein with reference to drawings that are schematic illustrations of idealized configurations. As such, variations from the shapes of the illustrations as a result, for example, manufacturing techniques and/or tolerances, are to be expected. Thus, the various aspects of the present disclosure presented throughout this document should not be construed as limited to the particular shapes of elements (e.g., regions, layers, sections, substrates, etc.) illustrated and described herein but are to include deviations in shapes that result, for example, from manufacturing. By way of example, an element illustrated or described as a rectangle may have rounded or curved features and/or a gradient concentration at its edges rather than a discrete change from one element to another. Thus, the elements illustrated in the drawings are schematic in nature and their shapes are not intended to illustrate the precise shape of an element and are not intended to limit the scope of the present disclosure.

It will be understood that when an element such as a region, layer, section, substrate, or the like, is referred to as being "on" another element, it can be directly on the other element or intervening elements may also be present. In contrast, when an element is referred to as being "directly on" another element, there are no intervening elements present. It will be further understood that when an element is referred to as being "formed" or "established" on another element, it can be grown, deposited, etched, attached, connected, coupled, or otherwise prepared or fabricated on the other element or an intervening element.

Furthermore, relative terms, such as “lower” or “bottom” and “upper” or “top” may be used herein to describe one element’s relationship to another element as illustrated in the drawings. It will be understood that relative terms are intended to encompass different orientations of an apparatus in addition to the orientation depicted in the drawings. By way of example, if an apparatus in the drawings is turned over, elements described as being on the “lower” side of other elements would then be oriented on the “upper” side of the other elements. The term “lower” can, therefore, encompass both an orientation of “lower” and “upper” depending of the particular orientation of the apparatus. Similarly, if an apparatus in the drawing is turned over, elements described as “below” or “beneath” other elements would then be oriented “above” the other elements. The terms “below” or “beneath” can therefore encompass both an orientation of above and below.

Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and this disclosure.

As used herein, the singular forms “a,” “an,” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprise,” “comprises,” and/or “comprising,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. The term “and/or” includes any and all combinations of one or more of the associated listed items.

Furthermore, various descriptive terms used herein, such as “transparent” should be given the broadest meaning possible within the context of the present disclosure. For example, something that is described as being “transparent” should be understood as having a property allowing no significant obstruction or absorption of electromagnetic radiation in the particular wavelength (or wavelengths) of interest, unless a particular transmittance is provided.

With reference initially to FIG. **1**, an example of a first sensor **100** will be described in accordance with embodiments of the present disclosure. The sensor **100** may be configured to operate as either a gesture sensor or a proximity sensor without departing from the scope of the present disclosure. The sensor **100** is shown to include a housing **104** having a top surface **108**, a plurality of side faces **112**, a front face **116**, and a back face **118**. In some embodiments the housing **104** is partitioned into two sections—a transmitter side and a receiver side. Accordingly, the housing **104** is depicted as further including a receiver hole **120** in the top surface **108** and a transmitter hole **124** in the top surface **108**.

In the example of the first sensor **100**, the top surface **108** is shown to be substantially parallel with the depicted x-y plane, the side faces **112** are shown to be substantially parallel with the x-z plane, and the front face **116** and back face **118** are shown to be substantially parallel with one another and with the y-z plane. Thus, the top surface **108** is substantially orthogonal with the side faces **112**, which are both substantially orthogonal with the front face **116** and back face **118**.

In accordance with at least some embodiments, the housing **104** may be constructed of any type of material that is suitable for attenuating or otherwise blocking light transmitted by a light source of the sensor **100**. Specifically, the housing **104** may provide two functions for the sensor **100**: (1) protection of the sensor **100** components and (2) preventing light from traveling directly from a light source of the sensor **100** to a light detector of the sensor **100**. Instead, the holes **120**, **124** may be configured as the light path for the sensor **100** and any light detected at the light detector may first travel through the transmitter hole **124**, then impact or reflect off an object, then travel through the receiver hole **120**. Any other light emitted by the light source of the sensor **100** is substantially inhibited from traveling to the light detector.

With reference now to FIGS. **2**A and **2**B, additional components of the first sensor **100** will be described in accordance with embodiments of the present disclosure. In particular, FIG. **2**A shows a sensor sub-assembly **200** or the sensor components that are housed within housing **104**. The sensor sub-assembly **200** is shown to include a substrate **204** with a receiver side **208** and transmitter side **212** mounted thereon.

The receiver side **208** is shown to include a receiver mold component **216**. As seen in FIG. **2**B, the receiver side **208** may also comprise a receiver Integrated Circuit (IC) **248**, a light detector **252**, and bonding wires **256** within the receiver mold component **216**. In some embodiments, the receiver mold component **216** corresponds to a plastic or similar type of material that is molded around the receiver IC **248**, light detector **252**, and bonding wires **256**, thereby encapsulating and protecting the components contained therein. In some embodiments, the receiver lens **220** may be integral to the receiver mold component **216**, meaning that the receiver lens **220** may be molded and formed of the same material as the rest of the receiver mold component **216**, but with a particular lens shape (e.g., a dome shape) that substantially focuses light toward the light detector **252**. In such an embodiment, the material of the receiver mold component **216** may be substantially transparent to wavelengths of light emitted by the transmitter side **212**. As an example, the receiver mold component **216** and/or receiver lens **220** may be substantially capable of allowing Infrared (IR) light or near-IR light to pass therethrough. In other embodiments, the receiver lens **220** is constructed of a different material from the rest of the receiver mold component **216**. In such a construction, the lens **220** may be substantially transparent to light emitted by the transmitter side **212** whereas the receiver mold component **216** may allow or block the light emitted by the transmitter side **212**. It may be generally desirable to utilize the construction where the receiver lens **220** is integral to the receiver mold component **216** to minimize assembly costs.

As seen in FIG. **2**A, an intermediate layer **240** may be provided between the receiver mold component **216** and the substrate **204**. The intermediate layer **240** may include structural components that support the receiver mold component **216** on the substrate **204**. The structural components of the intermediate layer **240** may include an insulative material that substantially supports the weight of the receiver IC **248** on the substrate **204** as well as provides an electrical separation between the receiver IC **248** and substrate **204**. Electrical connections between contacts of the substrate **204** and the receiver IC **248** may be facilitated by the bonding wires **256** that extend from a top surface of the receiver IC **248** to a top surface of the substrate **204**. In some embodiments, the area provided on the top surface of the substrate **204** that is used for establishing electrical connections with the receiver IC **248** may be absent the insulative material of the intermediate layer **240**.

In some embodiments, the substrate **204** may correspond to a Printed Circuit Board (PCB) or the like that supports the components of the receiver side **208** and transmitter side **212**. The substrate **204** may either be rigid or flexible. Moreover, the substrate **204** may comprise one or more conductive vias (not shown) that extend from a top surface of the substrate **204** to an opposing bottom surface of the substrate **204**. The bottom surface of the substrate **204** may further include one or more bonding pads **236** that enable the sensor **100** to be electrically connected to a larger PCB or some other electrical device. Thus, the electrical signals carried by the bonding wires **256** may be carried through the substrate **204** to the bonding pads **236** where they can be communicated to a larger circuit or set of circuits. In some embodiments, the bonding pads **236** may correspond to surface mount leads that enable the sensor **100** to be surface mounted to another PCB. Alternatively or additionally, the bonding pads **236** may comprise an array of bonding elements (e.g., a Ball Grid Array (BGA) or the like) that facilitate electrical connectivity between the sensor **100** and another PCB.

The transmitter side **212** of the sensor sub-assembly **200**, much like the receiver side **208**, may comprise a transmitter mold component **224** and one or more optical elements configured to direct light emitted by a light source of the transmitter side **212**. In the depicted embodiment, the optical elements of the transmitter side **212** include a lens having a wedge portion **228** and a pill portion **232** that is seamlessly integrated with the wedge portion **228**. As will be discussed in further detail herein, the unique configuration of the wedge portion **228** and pill portion **232** enable the light transmitted by a light source **260** of the transmitter side **212** to be transmitted at an off-axis angle with respect to the major surface of the substrate **204** and with respect to a light-emitting surface of the light source **260**.

Like receiver mold component **216**, the transmitter mold component **224** may be constructed of an optically-transparent and moldable material such as plastic, epoxy, glass, etc. In some embodiments, the wedge portion **228** and/or pill portion **232** may both be constructed from the same material as the transmitter mold component **224** and may even be integral with the rest of the transmitter mold component **224**. In other words, a single continuous material may be molded to create the wedge portion **228**, the pill portion **232**, and the rest of the transmitter mold component **224** that extends to the boundaries of the substrate **204**. It should be appreciated, however, that one or both of the wedge portion **228** and pill portion **232** may be constructed separate from the rest of the transmitter mold component **224** and may be attached thereto during a later manufacturing step. The transmitter mold component **224** may substantially encapsulate and protect the light source **260** and wire bonds established between the light source **260** and the substrate **204**.

Also like the receiver mold component **216**, the transmitter mold component **224** may be attached to the substrate **204** by an intermediate layer **244**, which may actually correspond to the same material as the intermediate layer **240**. Furthermore, one or more bonding wires **264** may be used to electrically connect the light source **260** to the substrate **204**. One or more electrical signals used to control operation of the light source **260** may be provided to the light source **260** via an external circuit (e.g., a sensor driver) that is connected to the light source **260** via the bonding pads **236**. In other words, the signals transmitted to the light source **260** may be carried from the bonding pads **236** through conductive vias in the substrate **204** to the bonding wire **264** and eventually to the light source **260**.

In accordance with at least some embodiments of the present disclosure, the light source **260** may correspond to any component or collection of components capable of producing and emitting light. As non-limiting examples, the light source **260** may comprise a Light Emitting Diode (LED), an array of LEDs, a laser diode, a collection of laser diodes, or the like. As a further non-limiting example, the light source **260** may correspond to a semiconductor-type light-emitting device that may or may not be constructed using flip-chip technology. In some embodiments, the light source **260** comprises a primary light-emitting surface (e.g., a top surface opposite the top surface of the substrate **204**) that is substantially parallel or planar with the x-y plane.

In accordance with at least some embodiments of the present disclosure, the light detector **252** may correspond to a photodetector, photodiode, a reverse-biased LED, a photoresistor, an image sensor (e.g., a CMOS image sensor), a Charge-coupled device (CCD), or the like that is mounted on the top surface of the receiver IC **248**. As a more specific, but non-limiting example, the light detector **252** may correspond an integrated optical circuit established on the IC **248** and a photodetector mounted on the IC **248**.

With reference now to FIG. **3**, additional details of the components included in the receiver side **208** will be described in accordance with embodiments of the present disclosure. The cross-sectional view of FIG. **3** along the x-z plane shows how the light detector **252** can be offset relative to the receiver lens **220** to help adjust the viewing angle of the receiver side **208**. Even more specifically, the lens center **304** is shown to be offset relative to a light detector center **308**. In some embodiments, no portion of the light detector **252** intersects or lies directly beneath the lens center **304**. By offsetting the lens center **304** from the light detector center **308**, the viewing window the receiver side **208** is directed away from directly above the light detector **252** as in prior art sensors. Instead, the viewing window is directed toward the front face **116** of the housing **104**, thereby enabling the light detector **252** to detect objects that do not lie directly above the lens center **304** or the light detector center **308**. In other words, the sensor **100** can be configured to view objects that are beyond the front face **116** of the housing **104**.

Another feature shown in FIG. **3** is that the receiver hole **120** is offset relative to a center of the substrate **204**. Said another way, the receiver hole **120** is established on the top surface **108** of the housing **104**, but is biased toward the front face **116**, which means that the receiver hole **120** is closer to the front face **116** than the back face **118**. Likewise, the lens center **304** is centered within the receiver hole **120**, which means that the receiver lens **220** is biased toward the front face **116** of the housing. Conversely, the light detector center **308** is biased toward the back face **118**, thereby creating an optical path that is angular relative to the top surface **108** of the housing **104** even though the light-detecting surface of the light detector **252** is substantially planar with the x-y plane, the optical path for the light detector **252** is not parallel with the z-axis.

With reference now to FIG. **4**, additional details of the components included in the transmitter side **212** will be described in accordance with embodiments of the present disclosure. The cross-sectional view of FIG. **4** along the x-z plane shows how the light source **260** can be offset relative to the lens elements of the transmitter side **212** as well as the substrate **204**. More specifically, and much like the receiver side **208**, the transmitter side **212** is configured such that a center of the light source **424** drawn through the center of the light source **260** and parallel with the z-axis is not coincident with the lens components of the transmitter mold component **224**. The pill portion **232** is shown to include a pill portion center **420** that is offset relative to the light source center **424**, thereby enabling the light emitted by the planar surface of the light source **260** to be directed away from the z-axis even though the light is initially transmitted from a light-emitting surface that is planar with the x-y plane.

In the depicted embodiment, lens components of the transmitter side **212** include wedge portion **228** and pill portion **232**. The wedge portion **228** is shown to include a wedge rear face **404** and a wedge front face **408**. The pill portion **232** is shown to include a cylindrical portion **412** and front end **416**. The pill portion center **420** substantially bisects the cylindrical portion **412** of the pill portion **232**. The wedge front face **408** interfaces with the cylindrical portion **412** such that a singular and integrated lens is created in the transmitter mold component. Along with the wedge rear face **404** and the front end **416** of the pill portion **232**, light emitted by the light source **260** is bent toward the front face **116** of the housing **104**. Thus, an object that is neither above the pill portion center **420** or the light source center **424** can be illuminated with light emitted by the light source **260**. In some embodiments, an object can be illuminated by the light source **260** and detected by the light detector **252** even when the object is not positioned above the transmitter hole **124** and possibly when the object is positioned beyond the front face **116** of the sensor **100**.

In some embodiments, the light source **260** is not aligned with the center of the substrate **204**. Instead, the light source **260** is biased toward the back face **118** of the housing **104**. Similarly, the light source **260** is biased toward the wedge portion **228** instead of the front end **416** of the pill portion **232**. This particular configuration enables light emitted by the light source **260** to be directed at an angle that is offset relative to the z-axis toward the front face **116**.

Also like the receiver hole **120**, the transmitter hole **124** is shown to be biased toward the front face **116** of the housing **104**. The offset of the transmitter hole **124** enables the bent light to be transmitted at the angle relative to the z-axis.

In some embodiments, the light source center **424** may not be exactly aligned with the light detector center **308** along the y-z plane; however, such a configuration could be possible. In other words, the light source center **424** may be closer or further away from the back face **118** than the light detector center **308** without departing from the scope of the present disclosure. Regardless of the relative position of the light source center **424** and light detector center **308**, the configuration of the lens elements enables the viewing angle of the sensor **100** to be directed away from a plane extending between the light source center **424** and light detector center **308** that is substantially orthogonal to the top surface of the substrate **104** (which consequently may also be orthogonal to the light-emitting surface of the light source **260** of the light-detecting surface of the light detector **252**). This means that objects do not have to be positioned over the sensor **100** (e.g., coincident with the lens center **304**, light detector center **308**, pill portion center **420**, or light source center **424**) to be detected by the sensor **100**. Advantageously, however, the structure of the sensor **100** components can still be substantially planar with respect to the substrate **204** on which they are mounted. This enables the sensor **100** to achieve a highly compact form factor while also enabling an extended and directional viewing window, thereby making the sensor **100** highly desirable for use in a number of electronic devices.

With reference now to FIGS. **5**-**8**, alternative configurations to that already described in connection with sensor **100**. In particular, FIG. **5** shows a sensor **500** configuration where a support **508** is used to tilt the entirety of the sensor package **504** away from the z-axis. This particular configuration can help achieve a directional sensor that views objects not directly above the base of the support **508**. The support **508** can be used in combination with the sensor **100** configuration described above or the support **508** can be used with a traditional on-axis sensor package where the light emitted by the light source is emitted directly orthogonal to the light-emitting surface of the light source and objects are required to be directly above the light-emitting surface of the light source to be detected.

FIG. **6** depicts another sensor **600** configuration where a receiver wedge **604** and transmitter wedge **608** are used to tilt the lens components of the receiver and transmitter, respectively. The receiver wedge **604** may tilt or rotate the lens components contained therein away from the z-axis. Likewise, the transmitter wedge **608** may tilt or rotate the lens components contained therein away from the z-axis thereby enabling the detection of objects off-axis from the sensor **600**.

FIG. **7** depicts another sensor **700** configuration where alternative configurations of a receiver lens **704** and transmitter lens **708** are used to direct light away from the z-axis, thereby enabling the sensor **700** to detect objects positioned away from directly over the light source and/or light detector. In some embodiments, the receiver lens comprises a cylindrical or pill portion that has a longitudinal axis parallel with the y-axis. The transmitter lens **708** may also comprise a cylindrical or pill portion that has a longitudinal axis parallel with the x-axis. These lenses may help to direct the viewing angle of the sensor **700** toward the front face **116** of the housing; however, because a wedge portion is not used, the viewing range and/or viewing window may not be as large as the viewing window achieved by sensor **100**.

FIG. **8** depicts another sensor **800** configuration where a planar or dome-shaped receiver lens **804** is used in combination with a cylindrical transmitter lens **808**. As with sensor **700**, the configuration of sensor **800** may achieve a certain amount of off-axis object detection, but the range and viewing window of the sensor **800** may be limited as compared to the range and viewing window of sensor **100**.

It should be appreciated that the sensors **500**, **600**, **700**, and **800** may not be as compact and/or have the same viewing range/window as sensor **100**.

With reference now to FIGS. **9A-D**, additional capabilities of a sensor **904** incorporated into an electronic device **900** will be described in accordance with embodiments of the present disclosure. The sensor **904** may correspond to any of the sensors **100**, **500**, **600**, **700**, and/or **800** described herein above. In some embodiments, the sensor **904** may correspond to the sensor **100** configuration having a highly compact form factor as well as the ability to detect or sense an object **908** that is not aligned above the sensor **904** with respect to the z-axis.

In some embodiments, the object **908** may correspond to any physical and/or movable element. As a non-limiting example, the object **908** may correspond to a limb, hand, finger, thumb, or the like of a user of the electronic device **900**. Alternatively or additionally, the object **908** may correspond to a stylus or other object having a predetermined shape. In some embodiments, the sensor **904** is configured to detect a proximity of the object **908** relative to the sensor **904** and/or the electronic device **900**. In some embodiments, the sensor **904** is configured to detect gesture inputs provided by a user by tracking a motion or series of motions of the object **908** relative to the sensor **904**. Advantageously, proximity or gesture can be detected with the sensor **904** even though the object **908** is not positioned directly above the sensor **904**.

In some embodiments, the object **908** does not have to cross the y-z plane that intersects the sensor **904**, which may also be referred to herein as the primary sensor plane. In other embodiments, the primary sensor plane may not be exactly coincident with the y-z plane, but, instead, may coincide with a plane established substantially perpendicular to the major surface of the substrate **204** and along a line extending between the light source and light detector of the sensor **904**. Another definition of the primary sensor plane may correspond to a plane that is perpendicular to the light-emitting surface of the light source (or the light-detecting surface of the light detector) and along a line extending between the light source and light detector of the sensor **904**. Under any definition, the primary sensor plane may basically travel through the sensor **904** and be approximately parallel with the y-z plane.

In some embodiments, the object **908** can be illuminated and detected by the sensor **904** when the object is displaced from the primary sensor plane intersecting the sensor **904** by a distance of DX. As an example, DX may correspond to a distance of at least six (6) inches; thus, the object **908** can be detected when it is six (6) inches away from the primary sensor plane. The object **908** can also be detected when it is displaced from a display screen **912** of the electronic device **900** by a height of H. In some embodiments, the object **908** may be detected even if the object is positioned more than 15 degrees away from the primary sensor plane. As shown in FIG. **9**D, the field of view of the sensor **904** does not even have to coincide with the primary sensor plane and the field of view may be at least 60 degrees wide. In other embodiments, the field of view of the sensor **904** may extend at least 80 degrees offset from the primary sensor plane (e.g., within 10 degrees of the display surface **912**) and the field of view can extend at least 6 inches away from the primary sensor plane. This particular field of view substantially enables the detection of the object **908** over the display screen **912** instead of over the sensor **904**, thereby increasing the potential gestures that can be captured with the sensor **904** for controlling operations of the electronic device **900**.

In some embodiments, the sensor **904** can be configured to detect the object **908** by illuminating the object **908** with light from the light source and then detecting light that reflects off the object with the light detector. In some embodiments, the reflected light from the object **908** can be detected by the light detector even though the reflected light has an obtuse angle of incidence relative to the primary sensor plane (e.g., the y-z plane passing through the light source and light detector). Moreover, the field of view may include the primary sensor plane as shown in FIG. **9**C, but the field of view is not required to coincide with the primary sensor plane as shown in FIG. **9**D and the maximum detection distance DMAX for an object may be as far away as 20 cm or more even when the object **908** is offset from the primary sensor plane by 45 degrees. In some embodiments, the object **908** may be detected even when the reflected light detected at the light detector arrives at the light detector at an acute angle of incidence measured relative to the light-detecting surface of the light detector. The reflected light detected at the light detector may then be correlated to at least one of a proximity and gesture input.

FIG. **10** further illustrates the optical operation of a sensor according to embodiments of the present disclosure. In particular, a sensor is configured to create an illumination area **1004** that is off-axis relative to the light-emitting surface of the light source and also off-axis relative to the primary sensor plane passing through the light source and light detector. Likewise, the light detector is configured such that the receiver's view window **1008** is also off-axis, but substantially aligned with the transmitter illumination area **1004** in an image plane **1000**. The image plane **1000** is neither orthogonal with the primary sensor plane nor is the image plane **1000** orthogonal with the light-emitting and/or light-detecting surfaces of the sensor's light source and/or light detector, respectively. Creating such an image plane **1000** enables the sensor to be utilized in a much more flexible manner than traditional light-based sensors.

Specific details were given in the description to provide a thorough understanding of the embodiments. However, it will be understood by one of ordinary skill in the art that the embodiments may be practiced without these specific details. For example, circuits may be shown in block diagrams in order not to obscure the embodiments in unnecessary detail. In other instances, well-known circuits, processes, algorithms, structures, and techniques may be shown without unnecessary detail in order to avoid obscuring the embodiments.

While illustrative embodiments of the disclosure have been described in detail herein, it is to be understood that the inventive concepts may be otherwise variously embodied and employed, and that the appended claims are intended to be construed to include such variations, except as limited by the prior art.

What is claimed is:

1. An optical sensor, comprising:

a substrate comprising a first major surface;

a light source mounted on the first major surface of the substrate and configured to emit illumination light away from the first major surface toward an object;

a light detector mounted on the first major surface of the substrate and configured to detect reflected light that is created as a result of the object being illuminated with the illumination light, wherein a primary sensor plane is established substantially perpendicular to the first major surface and along a line extending between the light source and light detector; and

a first optical element positioned between the light source and object, the first optical element being configured to project the illumination light away from the primary sensor plane such that the object is illuminated even when the object is positioned more than 15 degrees away from the primary sensor plane.

2. The optical sensor of claim **1**, wherein the light detector comprises a field of view that does not coincide with the primary sensor plane.

3. The optical sensor of claim **2**, wherein the field of view is at least 60 degrees wide.

4. The optical sensor of claim **2**, wherein a bottom of the field of view is at least 80 degrees offset from the primary sensor plane.

5. The optical sensor of claim **2**, wherein the field of view extends at least 6 inches away from the primary sensor plane.

6. The optical sensor of claim **1**, further comprising:

a second optical element positioned between the object and the light detector, wherein the second optical element comprises a dome-shaped lens and wherein the light detector is not positioned beneath a center of the dome-shaped lens.

7. The optical sensor of claim **1**, wherein the light source and light detector are positioned offset from a center axis of the substrate.

8. The optical sensor of claim **1**, wherein the light source is mounted directly to the substrate.

9. The optical sensor of claim **1**, wherein the first optical element comprises a lens with a wedge portion, a dome-shaped end, and a cylindrical section connecting the wedge portion with the dome-shaped end.

10. The optical sensor of claim **9**, wherein the lens completely encapsulates the light source and wherein the lens comprises at least one of epoxy, silicone, a hybrid of silicone and epoxy, phosphor, a hybrid of phosphor and silicone, an amorphous polyamide resin or fluorocarbon, glass, and plastic.

11. A communication device comprising the optical sensor of claim **1**.

12. An optical system for detecting at least one of proximity and gesture, the system comprising:

a light source comprising a first major surface configured to emit illumination light toward an object;

a light detector configured to detect reflected light that is created as a result of the object being illuminated with the illumination light, wherein a primary sensor plane is established substantially perpendicular to the first major surface and along a line extending between the light source and light detector, wherein the light detector comprises a field of view that does not coincide with the primary sensor plane;

a first optical element positioned between the light source and the object, the first optical element being configured to project the illumination light away from the primary sensor plane such that the object is illuminated even when the object is positioned more than 15 degrees away from the primary sensor plane; and

a second optical element positioned between the object and the light detector, wherein the second optical element is discrete and separate from the first optical element.

13. The system of claim **12**, wherein the field of view is at least 60 degrees wide and offset from the primary sensor plane by at least 15 degrees.

14. The system of claim **12**, wherein the field of view is offset from the primary sensor plane by at least 30 degrees.

15. The system of claim **12**, wherein the detected reflected light is correlated to a gesture input.

16. The system of claim **12**, wherein the reflected light detected at a light-detecting surface of the light detector comprises an angle of incidence as small as 10 degrees measured relative to the light-detecting surface of the light detector.

17. The system of claim **12**, wherein the light source comprises a Light Emitting Diode (LED) and wherein the light detector comprises a photosensor positioned on an Integrated Circuit.

18. The optical sensor of claim **1**, wherein the light source comprises a Light Emitting Diode (LED) and wherein the light detector comprises a photosensor positioned on an Integrated Circuit.

19. The optical sensor of claim **1**, wherein the detected reflected light is correlated to a gesture input.

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